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Index estimates of abundance for beluga in eastern Hudson Bay, James Bay and Ungava Bay in Summer 2008

Indices de l'abondance des bélugas dans l'est de la baie d'Hudson, la baie James et la baie d'Ungava à l'été 2008

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ABSTRACT

The management of beluga whales hunted around Nunavik relies on the estimation of abundance of summering stocks, including the endangered Ungava Bay and eastern Hudson Bay stocks. Systematic aerial line-transect surveys to estimate abundance of beluga whales were conducted in James Bay, eastern Hudson Bay and Ungava Bay from 20 July to 28 August 2008. The flights followed east-west lines with a spacing of 18.5 km in all strata except in the central portion of eastern Hudson Bay, a high coverage area where spacing was reduced by half, *i.e.* 9.3 km, and the stratum was surveyed twice. A total of 279 beluga clusters was detected between perpendicular distances of 120 m to 2880 m from the track line. The hazard-rate model (AIC = 4145.3) with a lower AIC than the half-normal model (AIC = 4156.9) fitted on the ungrouped perpendicular distance distribution provided an effective strip half width of 839 m (cv = 0.08). Abundance indices were not corrected for availability of diving animals nor for the observer perception. A total of 214 clusters with an average size of 3.99 (cv = 0.31) were detected on 4,279 km of lines in James Bay providing an abundance index of 9,292 (cv = 0.64). A single animal was seen over the 1,246 km surveyed in the low coverage area of eastern Hudson Bay for an abundance index of 13 (cv = 1.02). A group of three animals over 82 km provided an abundance index of 15 (cv =1.03) in the Richmond Gulf (Lac Guillaume-Delisle). There were 2.8 times more beluga whales detected on the first survey of the high coverage area of eastern Hudson Bay than on the second survey of the same area, with 107 clusters of an average size of 2.97 (cv = 0.13) and 45 groups with an average size of 2.49 (cv = 0.30) for the first and second survey, respectively. The abundance indices of 1,797 (cv = 0.27) and 657 (cv = 0.38) for the first and second surveys respectively, provided an average, weighted by effort, of 1,237 (cv = 0.46). No whales were seen in the estuaries of the Nastapoka and Little Whale rivers during coastal surveys. The addition of the low coverage area and Richmond Gulf abundance indices to the weighted average of the two surveys in the high coverage area provided an abundance index for the whole eastern Hudson Bay of 1,265 (cv = 0.45). Beluga whales were not detected in Ungava Bay despite the 4,334 km of offshore survey lines, the coastal surveys done between transect lines and the surveys of the estuaries of the Mucalic, False, George and Koksoak Rivers. Beluga whales were also not detected during the coastal survey of the Hudson Strait from Quaqtaq to Inukjuak conducted on 27 and 28 August. This is the fifth visual systematic survey of James Bay and eastern Hudson Bay. Differences in the surface abundance indices among years and between surveys of the high coverage area of eastern Hudson Bay in 2008, illustrate the challenges to estimate the abundance of small populations with clumped distributions.

RÉSUMÉ

La gestion des bélugas chassés au Nunavik repose sur l'estimation de l'abondance des stocks y passant l'été, soit les stocks de la baie d'Ungava et de l'est de la baie d'Hudson qui sont tous deux en danger de disparition. Des relevés systématiques aérien d'échantillonnage en ligne pour estimer l'abondance des bélugas furent complétés dans la baie James, l'est de la baie d'Hudson et la baie d'Ungava du 20 juillet au 28 août 2008. Les vols suivaient des lignes d'orientation est-ouest avec un espacement de 18.5 km dans toutes les strates sauf dans la partie centrale de l'est de la baie d'Hudson, zone de couverture intense où l'espacement était réduit de moitié, *i.e.* 9.3 km, et où la strate fut survolée deux fois. Un total de 279 groupes de bélugas furent détectés entre les distances perpendiculaires au trajet de l'avion de 120 m à 2880 m. Le modèle "hazard-rate" (AIC = 4145.3), avec un plus bas critère d'information d'Akaike (AIC) que le modèle demi-normale ("half-normal", AIC = 4156.9), ajusté sur la distribution des distances perpendiculaires non-regroupées a fourni une demi-largeur de bande de détection efficace de 839 m (cv = 0.08). Les indices d'abondance n'ont pas été corrigés pour le biais de disponibilité pour les animaux en plongée ni pour le biais de détection des observateurs. Un total de 214 groupes avec une taille moyenne de 3.99 (cv = 0.31) furent détectés sur 4 279 km de lignes dans la baie James produisant ainsi un indice d'abondance de 9292 (cv = 0.64). Un seul animal détecté sur 1246 km de survol dans la zone de faible couverture de l'est de la baie d'Hudson a produit à un indice d'abondance de 13 (cv = 1.02). Un groupe de 3 animaux détecté sur 82 km a produit un indice d'abondance de 15 (cv = 1.03) dans le Lac Guillaume-Delisle (Richmond Gulf). Il y a eu 2.8 fois plus de bélugas détectés lors du premier relevé que lors du second relevé de la zone de couverture intense de l'est de la baie d'Hudson, avec respectivement 107 groupes de taille moyenne de 2.97 (cv = 0.13) et 45 groupes de taille moyenne de 2.49 (cv = 0.30) pour le premier et le second relevé. Les indices d'abondance respectifs de 1797 (cv = 0.27) et de 657 (cv = 0.38) pour le premier et second relevé correspondent à un indice moyen pondéré pour l'effort de 1237 (cv = 0.46). Aucune baleine fut observée dans les estuaires de la rivière Nastapoka et de la Petite-Rivière-à-la-baleine pendant les relevés côtiers. L'addition des indices d'abondance de la zone de faible couverture et du Lac Guillaume-Delisle à la moyenne pondérée des deux relevés de la zone de couverture intense ont produit un indice d'abondance de 1265 (cv = 0.45) pour l'ensemble de l'est de la baie d'Hudson. Aucun béluga ne fut détecté dans la baie d'Ungava malgré 4334 km de lignes survolées au large des côtes, les relevés côtiers et le survol des estuaires des rivières Mucalic, False, George et Koksoak. Aucun béluga ne fut détecté pendant le relevé côtier du détroit d'Hudson de Quaqtaq à Inukjuak réalisé le 27 et 28 août. Ceci est le cinquième relevé visuel systématique de la baie James et de l'est de la baie d'Hudson. Les variations dans les indices d'abondance de surface entre les années et entre les relevés de la zone de couverture intense dans l'est de la baie d'Hudson en 2008 illustrent les défis liés à l'estimation d'abondance de petites populations avec des distributions regroupées.

INTRODUCTION

Beluga whales, *Delphinapterus leucas*, in eastern Canadian subarctic waters are observed during the summer along both coasts of Hudson Bay, in James Bay and in Ungava Bay. Molecular genetic studies indicate at least two stocks: a western Hudson Bay stock and an eastern Hudson Bay stock (Brennin et al. 1997; Brown Gladden et al. 1997; De March & Postma 2003). The relationships between beluga whales in these regions and those found in James Bay, around the Belcher Islands, in northwestern Hudson Bay, and along the Ontario coast of Hudson Bay are unclear (Richard et al. 1990; Richard 2005).

Commercial whaling during the eighteenth, nineteenth, and early twentieth centuries probably initiated the decline of beluga stocks in northern Quebec, but high subsistence harvests likely limited the potential for stocks to recover (Doan & Douglas 1953; Finley et al. 1982; Reeves & Mitchell 1987a; Reeves & Mitchell 1987b). Concerns for beluga in eastern Hudson Bay and Ungava Bay led to their designation as 'endangered' by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2004;Reeves & Mitchell 1989; Richard 1993).

Beluga harvesting represents a traditional activity for native people living along the coasts of Nunavik. Beginning in 1986, limits were placed on harvesting as a result of low estimates of beluga abundance in eastern Hudson Bay and Ungava Bay. In spite of these controls, population modelling incorporating harvest information since 1974, and fitted to data from three aerial surveys flown during the period 1985–2001 indicated a decline in the number of beluga in eastern Hudson Bay by almost half since 1985 (Hammill et al. 2004). More stringent management measures were implemented, including complete closures of eastern Hudson Bay and Ungava Bay in some years (Lesage et al. 2009). In 2004, another aerial survey was conducted in James Bay and eastern Hudson Bay, and a modelling exercise similar to the one conducted in 2001 indicated that the rate of decline of the population had likely slowed (Hammill et al. 2005; Gosselin 2005).

Beluga harvesting by Nunavik Inuit has been managed under the jurisdiction of DFO. The signing of the Nunavik Unuit Land Claims Agreement (NILCA) will transfer management responsibility to a wildlife Management Board established under the agreement. Until the new management board is operational, a new management plan will be implemented in spring of 2009, and will be based on a review of recently acquired scientific information. In this context, the current study presents abundance indices obtained from systematic line-transect aerial surveys conducted during summer 2008 in James Bay, eastern Hudson Bay and Ungava Bay.

MATERIALS AND METHODS

Study area and design

The visual line-transect survey flown in summer of 2008 covered all of James Bay, the eastern Hudson Bay arc from the coast to 81°W of longitude which is 60 km west of the Belcher Islands, and the Ungava Bay from the bottom of the bay to 61°03' N (Figures 1 and 2). We used the same stratification in James Bay and eastern Hudson Bay as used for the last survey in 2004 (Gosselin 2005). The limits of each stratum lies in regions of relatively low density based on previous surveys and of low frequentation in summer according to satellite tracking of beluga whales captured in eastern Hudson Bay and James Bay (Hammill, unpublished data). Transect lines were oriented in an east-west direction. There were 24 lines in James Bay, 8 lines in the low coverage area of eastern Hudson Bay and 27 lines in the high coverage area that were surveyed twice (Figure 1). There were 14 lines in the high coverage area in southern Ungava Bay and 10 lines in the low coverage area of Ungava Bay (Figure 2). Lines in James Bay and in the low coverage areas of eastern Hudson Bay and Ungava Bay were spaced 18.52 km (10 nautical miles) apart, whereas spacing in the high coverage areas of eastern Hudson Bay and Ungava

bay was 9.26 km (5 nautical miles). The length of transect lines (used to estimate density) and the area of strata (used to estimate abundance) were both estimated on Universal Transverse Mercator (UTM) projection using GIS (Arcview 3.2). We used UTM zone 17, with 81° W as the central meridian for James Bay and eastern Hudson Bay and UTM zone 19, with 69°W as the central meridian for Ungava Bay. The areas of each stratum and the total effort in km of lines are given in Table 1. The intent was to survey the high coverage areas of eastern Hudson Bay twice and the low coverage areas of James Bay, eastern Hudson Bay and Ungava Bay once using the systematic line transect design, and to cover the Hudson Strait area through a coastal survey similar to the one conducted in 2001 (Gosselin et al. 2002).

Coastal surveys were flown while on transit between lines and between lines and the airports in James Bay, eastern Hudson Bay and Ungava Bay. In eastern Hudson Bay, the estuaries of the Little Whale River and of the Nastapoka River were visited every time a transit was passing by, weather permitting. After all the systematic surveys had been completed, a coastal survey of Hudson Strait was completed from Quaqtaq to Inukjuak. During coastal surveys, the planes were flying at an offshore distance where observers were comfortable that they would detect all animals from the plane to the coast.

Data collection

Flights were conducted using two Cessna-337 skymasters equipped with three bubble windows and flying at a target altitude of 304.8 m (1000 feet) and a target speed of 185.2 km/h (100 kts). Each plane was flying every second line of the survey design. At least two observers were continuously onboard the plane, one in the co-pilot seat and one behind the pilot. An Inuit observer was also present behind the co-pilot observer for most of the flights. All observers received training on the ground on 16 July, which was followed by a training flight along twenty-seven lines perpendicular to the main axis of the St Lawrence estuary on 17 July. This trial allowed the observers to become familiar with data sampling in areas of high densities of beluga whales.

Observers measured distances using inclinometers (Suunto) when animals passed abeam. When groups were detected away from the transect line, the angle relative to bearing was also measured using an anglemeter. Position and altitude of the plane were recorded every 10 s using a GPS (Garmin GPS 76, GPS Map 60C) connected to a laptop running an electronic map software (Fugawi). Observers were instructed to give priority to the estimation of group size, especially when beluga densities were high, followed by perpendicular distance and the other variables if time permitted. Transects were generally flown in passing mode, but closing mode or multiple passes were done for some very large concentrations detected from the lines.

Weather and observation conditions were also recorded at the beginning, at the end and at regular intervals along the lines or whenever changes in sighting conditions were detected. The conditions noted included sea state (Beaufort scale), subjective visibility (4 levels: excellent, good, medium, reduced, none), angle of searching area affected by sun reflection along with sun reflection intensity [4 levels: 1- intense when animals were certainly missed in the center of reflection angle; 2- medium when animals were likely missed in the center of reflection angle, 3- low when animals were likely detected in center of reflection angle and 4- none when there was no reflection]. An index of reflection coverage was also used and was defined as angle of reflection divided by 180° and multiplied by reflection intensity with values of 1 for intense, 0.5 for medium, 0.25 for low and 0 for none. All the information was recorded on tapes by each observer and was entered on computers in the evenings or on days of bad weather.

Data analysis

The density and abundance were estimated using the software Distance (Version 5.0, Release 2; Thomas et al. 2006). The analyses were completed using the ungrouped distances and clusters defined as groups of beluga whales within a few body lengths of each other.

The overall distribution of perpendicular distances was examined for left and right truncations, which were determined to discard only the outliers close to and away from the trackline. The detection curve was selected between half normal and hazard rate models using AIC. As the survey was conducted with the same observer crew from the practice to the end of the survey and since the conditions criteria to fly the survey remained the same throughout the survey a single detection curve was used to estimate density and abundance in all strata.

The expected cluster size in each stratum was estimated using the size bias regression method of the natural log of cluster size against the probability of detection (Ln(s) vs g(x)). The regression was used if significant at α = 0.15; otherwise the mean cluster size was used (Buckland et al. 2001).

For the counts of large concentrations of beluga whales made in closing mode, the maximum of count of the single pass was used as group size, as double counts on each pass are unlikey, but we acknowledge that whales were missed, especially those under the plane. These large concentrations were actually high densities of the usual smaller clusters, which as previously mentioned, were defined as small groups of individuals within body lengths of each other. To use as much as of the information as possible, perpendicular distances and cluster sizes, measured on the first pass were used to evaluate if the probability of detection varied with cluster sizes [re. evaluation of the regression ln(s) vs g(x)]. The difference between the maximum count of the passes with the count from the first pass was then added as a group in the estimation of density. These differences in counts had no associated perpendicular distance, and were not used in the estimation of the detection function, nor in the evaluation of relationships of ln(s) vs g(x).

As observers were instructed to give priority to group size estimation some observations were lacking a perpendicular distance measurement when high densities of beluga whales were encountered. These observations were not included in the estimation of detection function nor in the regression of natural log of cluster size against probability of detection [Ln(s) vs g(x)]. However, these observations were all assumed to be within truncation distances as we expect that the effective searching width to be narrowed in higher densities and they were included in the estimation of encounter rate and expected cluster size for the estimation of density and abundance. This was done in Distance by adding all observations without perpendicular distance to observations within truncation distances and by fitting a uniform model with the following multipliers estimated from observations within truncation distances: the estimated probability of detection, P (along with SE and degrees of freedom) which is associated with the estimation of the effective strip half width (ESHW) and a constant truncation multiplier [= right truncation/(right truncation - left truncation)].

The estimated index of density ($\hat{D}$) and abundance ($\hat{N}$) of beluga whales at the surface during systematic survey of each stratum are estimated in Distance using the following formulae:

$$\hat{D} = \frac{n \cdot \hat{E}(s)}{2L \cdot ESHW} \qquad (1)$$

$$\hat{N} = \hat{D} \cdot A \qquad (2)$$

where n is the number of groups detected, $\hat{E}(s)$ is the expected cluster size in the stratum, L is the sum of lenghts of all transects in the stratum and A is the area of the stratum. The associated variance of density and abundance of animals at the surface during systematic survey is estimated by:

$$\text{var}(\hat{D}) = \hat{D}^2 \cdot \left[\frac{\text{var}(n)}{n^2} + \frac{\text{var}(ESHW)}{[ESHW]^2} + \frac{\text{var}(\hat{E}(s))}{[\hat{E}(s)]^2}\right] \quad (3)$$

The distribution of density is assumed to be log-normally distributed, and the 95% CI was estimated using:

$$\left(\hat{D}/C, \hat{D}\cdot C\right) \quad (4)$$

where

$$C = \exp\left[t_{df}(\alpha)\cdot\sqrt{\text{var}(\ln\hat{D})}\right], \quad (5)$$

$$\text{var}(\ln D) = \ln\left[1 + \frac{\text{var}(\hat{D})}{\hat{D}^2}\right] \quad (6)$$

and where $t_{df}(\alpha)$ is the critical value of Student's t-distribution at α= 0.05. To consider the few degrees of freedom of some component of variance, the degrees of freedom were computed according to the Satterthwaite (1946) method adapted by Buckland et al (2001):

$$df = \frac{\left[\sum_q [cv_q]^2\right]^2}{\sum_q [cv_q]^4 / df_q} \quad (7)$$

where the coefficient of variation and degrees of freedom are estimated for each of the q components of the estimation of density, which are: n, ESW and $E(s)$.

The abundance estimates from the two passes in the high coverage area of eastern Hudson Bay, N_j were combined to provide an estimate of abundance in the high coverage strata, N_s, for 2008. Average abundance was weighted by effort (*i.e.*, total length of transects for each pass j = L_j). The variance was estimated using the variation of abundance between passes (modified from equations 3.84 to 3.87 in Buckland et al. 2001, treating the passes as samples):

$$N_s = \frac{\sum_{j=1}^{d} L_j N_j}{L_s} \quad (8)$$

$$\text{var}(N_s) = \frac{\sum_{j=1}^{d}\left[L_j (N_j - N_s)^2\right]}{L_s (d-1)} \quad (9)$$

where L_s is the total length of transects for both passes and d is the number of passes; two in this case. The total for eastern Hudson Bay was obtained by the addition of low coverage area, the Richmond Gulf and the average of the two passes in the high coverage area. The confidence

interval was estimated assuming a log-normal distribution of densities (equations 3.72 to 3.74 in Buckland et al. 2001).

RESULTS

Systematic line-transect survey

The survey of James Bay was conducted generally from the southern to northern transects which were entirely completed without interruption from the 20 July to the 22 July, 2008. We then proceeded to eastern Hudson Bay with the low coverage area and the first pass of the high coverage area completed by 9 August. There were 3 interruptions during that time: a 5 day delay from the 26 July to the 30 July after seven lines including line 5602, a 2-day delay on 2 and 3 August when we had completed line 5702 in front of the Nastapoka River, and finally a 5-day delay on 3 to 7 August when we were at the northern end of the high coverage area. The second pass of the high coverage area of eastern Hudson Bay was completed from 11 to 19 August. There was a 2-day delay in the central part of the high coverage area of eastern Hudson Bay after northern lines to line 5627 and two lines to the south, 5542 and 5532, were completed. All remaining lines were completed without delays. However, on that second pass, the western end of three lines, west of the Belcher Islands, were never completed due to fog (51 km on line 5557, 58 km on line 5607 and 42 km on line 5617). Another 26 km of the eastern end of line 5532 was also never completed due to fog. We surveyed the Richmond Gulf on the 19 August. The Ungava Bay was completed from the 20 to 28 August, with one 4-day delay on 22 to 25 August after line 5853 and all the lines to the south had been completed. The remaining lines were completed without delay from the 26 to 28 August. The eastern end of 5 lines were never completed due to fog in the north-eastern end of the bay, i.e. 48 km of line 5953, 47 km of line 6003, 47 km of line 6013, 44 km of line 6023 and 18 km of line 6043.

The coastal survey of Hudson Strait was flown on the 27 August from Quaqtaq to Kangiqsujjuaq and completed from Kangiqsujjuaq to Inukjuak on the 28 August. No beluga whales were seen during that coastal survey.

A total of 368 groups corresponding to 1300 individual beluga whales were detected on transect lines. A total of 214 clusters and 853 individuals were detected while on effort in James Bay. The 108 groups for 326 beluga whales detected on the first pass of eastern Hudson Bay represented 2.4 times more clusters and 2.7 times more individuals than the 47 groups for 120 beluga whales detected on the second survey (Table 1). There was only one animal seen in the northern part of the lower coverage area of eastern Hudson Bay, and one cluster of 3 beluga whales detected while on effort in Richmond Gulf. No beluga whales were seen in Ungava Bay. However, one minke whale, two bowhead whales 56 white-beaked dolphins more than 750 harp seals and one swimming polar bear were detected in this area.

Some beluga whales were seen during coastal surveys in eastern Hudson Bay. A group of 16 beluga whales was seen 2.5 km south of the Little Whale River estuary on the 18 August, the day when lines 5607, 5617, 5602 and 5552 were flown. The following day (19 August), a group of 48 animals was detected 2.2 km north of the Little Whale estuary and a second group of 43 animals was detected along the coast 23 km south of the estuary. However these groups were not in the estuary *per se*. The Little Whale estuary was visited 8 times on 4 different days over the course of the two surveys in central eastern Hudson Bay, and these encounters were the only two occasions when large groups were seen within 20 km from the mouth of the river. The Nastapoka River estuary was visited 5 times on 5 different days, and no beluga whales were seen in the estuary. As no beluga whales were seen in the estuaries, no coastal counts were added to the systematic offshore estimate.

Out of the 368 groups sighted during the eastern Hudson Bay/James Bay surveys, 282 groups had perpendicular distances measurements. Eighty-three of the 86 groups missing perpendicular distances were seen in James Bay, including 76 groups which were encountered within a period of 2 min 27 s, or over 4.8 nautical miles. Animals were not detected under the plane and only two groups, for a total of 15 individuals, were detected within 120 m of the trackline. This distance was used as the left-truncation. Beluga whales were detected regularly as far as 2880 m away, a distance which was used as the right truncation, and which discarded only one animal with an estimated detection distance of 4275 m. Buckland and colleagues (2001) suggest to truncate observations further than the distance to which the hazard rate model on overall distances estimates a probability of detection equal to 0.15. However, according to the Cramer-von Mises test with cosine weighting function, the fit near the trackline did not improve from truncation to 1592 m ($\rho = 0.66$) instead of 2880 m ($\rho = 0.74$). Therefore, the latter value was kept as the right truncation distance. Hazard-rate was selected as the key function model as it provided a lower AIC (4145.31) than the half-normal model (AIC = 4156.93) when applied over the 279 observations remaining between the truncations distances of 120 m to 2880 m from the trackline and provided an effective strip half width of 839 m. Given these truncation distances and the detection function, the multipliers to apply to the uniform model to include observations without truncation distances were an estimated probability of detection, $\hat{P}$ of 0.29141 (SE = 0.02469, df = 277) and a truncation multiplier of 1.0435.

Five large groups were estimated using closing mode and the maximum count of all passes on these concentrations was used as cluster size. Three of these groups were in James Bay, with group sizes of 214, 158 and 113. Several passes were done for one group of 46 detected on the first survey of eastern Hudson Bay and a group of 33 detected on the second survey of eastern Hudson Bay. The 214 groups detected in James Bay had a mean cluster size of 3.99 (CV = 31%). The high 31% coefficient of variation comes from the fact that large numbers of beluga whales were counted in few large clusters including two groups of 158 and 214 beluga whales (Figure 4). Mean cluster size was lower in the higher coverage area of eastern Hudson Bay than in James Bay. However, this metrics varied between the two passes in the area, as mean cluster size was higher but less variable (2.97 beluga whales, CV = 13%) during the pass where a higher number of groups were encountered, and lower and more variable (2.49 beluga whales, CV = 30%) during the pass with fewer sightings. In this second pass, all except one group of 33 beluga whales included 10 individuals or less (figure 4). In comparison, cluster size was more evenly distributed during the first pass, with groups of 24 beluga whales or less (Figure 4). None of the stratum showed a significant regression of the natural log of cluster size with the probability of detection and mean cluster size was used as the expected cluster size $\hat{E}(s)$ in the estimations of densities.

The encounter rate is the last of the three components of density and abundance estimation. In James Bay a total of 214 groups were detected within the truncation distances and including groups without distances. Most of these groups were detected just north and south of Akiminski Island with 58% (125/214) of these groups detected ten nautical miles north of the island on line 5322, and another 19% (40/214) detected just south of the island on line 5242 (Figure 5). The high proportion of sightings on these two lines contributed largely to the high 0.56 coefficient of variation associate with the estimation of encounter rate in James Bay. In eastern Hudson Bay, there was a large reduction to 42% of the number of groups detected on the second survey compared to the first survey in the high coverage density area. It also seemed that there was a slight shift to the north in the distribution of the animals (Figures 6 and 7). The number of clusters was more evenly distributed between lines than it was in James Bay which resulted in lower coefficient of variations of 0.22 and 0.21 on the first and second survey respectively. The average encounter rate in James Bay (0.0500 groups/km) is 4.3 times higher than the average encounter rate of the two surveys of the high coverage area of eastern Hudson Bay (0.0115 groups/km).

The density and abundance indices for each stratum were not corrected for diving animals nor for perception bias and is therefore the number of animals detected at the surface by

a single platform (Table 2). The high coefficient of variation of 0.64 observed in James Bay is associated with high clumping of beluga whales in the area as revealed by the high coefficient of variations associated with the estimation of both encounter rate (0.56) and cluster size (0.31). The surface index of abundance in the high coverage stratum of eastern Hudson Bay was 2.7 times higher during the first than the second pass. This resulted in a mean index of 1,237 beluga whales for this stratum with a coefficient of variation for the averaged index of 0.46 that was higher than the coefficient of variations of 0.27 and 0.38 for the first and second survey respectively. Adding the surface estimates of 13 and 15 beluga whales from the low coverage area and Richmond Gulf resulted in an overall index of abundance at the surface of 1,265 beluga whales (95% CI: 545 - 2,939) in eastern Hudson Bay (Table 2).

DISCUSSION

The survey conducted in 2008 is the fifth of a series of systematic surveys undertaken since 1985 in James Bay and waters surrounding Nunavik (Smith & Hammill 1986; Kingsley 2000; Gosselin et al. 2002; Gosselin 2005). The 2008 estimate of abundance of beluga in James Bay is the highest but was less precise than that in 1985. It was 2.3 times as high as the estimate obtained four years before for the same region with a similar design. This would correspond to a rate of increase of approximately 18% per year, a rate much higher than the 2-3% generally assumed for beluga and other species with similar life history (Kingsley 1989; Barlow & Boveng 1991; Kasuya et al. 1988; Hammill et al. 2004). However, compared to the 2001 survey estimate, it represents an annual rate of increase of 1.7% (Table 3). The coefficient of variation of 0.64 associated with the estimates of abundance of 2008 in James Bay was higher than for all previous surveys of the area which varied from 0.20 to 0.27.

However, in the adjacent region to the north, the abundance estimate of beluga in eastern Hudson Bay in 2008 was the lowest since 1985 but it was within the 95% confidence interval of all of these surveys. It was approximately 38% lower than the 2004 estimate, and then 10% and 11% lower than those obtained in 1993 and 2001 respectively. The survey effort was almost twice as important in eastern Hudson Bay in 2008 compared to previous years. The annual estimate included the effort weighted average of two abundance estimates of the high beluga density area of the Hudson Bay Arc. These two abundance estimates from the same lines surveyed only days apart varied by a factor of 2.7. The objective of the two surveys of eastern Hudson Bay was to provide an annual abundance estimate with a reduced variance, but the two estimates were so different that the combined coefficient of variation was higher than for each survey (Table 2). The coefficient of variation for eastern Hudson Bay in 2008 (0.45) was similar to the coefficient of variation obtained in 2001 (0.45) but slightly higher than in 1993 (0.37) and 2004 (0.34) (Table 3).

Possible problems that were suggested with the 2004 survey did not occur or were of less concern in 2008. A logistics problem with the survey in 2004 was the change in observer crew during the survey with observers with variable survey experience. In 2008, the same observers were present from the practice in the St Lawrence estuary to the last day of survey and all observers had previous survey experience either from boats or from boats and planes. Another factor that was of concern in 2004 was the presence of long delays during the eastern Hudson Bay survey which was completed in 24 days from the 7 August to 30 August. In 2008, the eastern Hudson Bay was completed in 29 days from the 22 July to 19 August. It took 5 more days in 2008 than in 2004, but two surveys of the high coverage area instead of only one were completed during that period. There were also concerns in 2004 that there might have been movements of animals from James Bay and southern Hudson Bay into eastern Hudson Bay due to the delays and the survey lasting to the end of August. In 2008, all surveys in eastern Hudson Bay were completed 11 days earlier than in 2004 therefore reducing the chances of movements from the southern regions. This earlier date also reduced the chances that migration from animals from eastern Hudson Bay had started, as movements from tagged animals have shown

that migration usually occurs in late September (Kingsley et al. 2001; Hammill unpublished data). Furthermore, since 2004, eight beluga whales have been tagged with satellite transmitters in James Bay, and none of them has shown movement into eastern Hudson Bay (Hammill unpublished data).

The imprecision of the estimates of abundance in 2008 illustrate the challenges related to the census of small populations with clumped distributions. When surveying populations with these characteristics, the number of groups detected on each transect, and the occurrence of a few large clusters that represent clumping at two different scales can have dramatic effects on abundance estimates. In Distance sampling, density and abundance estimates result from the multiplication of three components and their associated variance: encounter rates, mean cluster size, and effective strip half width (equations 1 and 3; see also Buckland et al. 2001). The impact of encountering a few large groups of beluga whales on mean cluster size is illustrated by the 75% increase in mean cluster size (from 2.27 to 3.99 beluga/cluster) caused by the two large clusters of 214 and 158 individuals encountered in James Bay (Figure 4). In other words, these two groups explained 44% of the James Bay abundance estimate. A similar but less dramatic effect was observed on the second pass over the high coverage area of eastern Hudson Bay, with a group of 33 beluga whales boosting cluster size by 39% (from 1.80 to 2.49 beluga whale/cluster). The effect of the number of encounters on transects is illustrated by the two passes over the same, high coverage area of eastern Hudson Bay, of what is in theory the same population. About 2.5 times more groups were detected during the first survey than during the second survey, resulting in an abundance estimate 2.7 times higher for the first survey. In a study on St Lawrence beluga whales, fourteen surveys were flown at two altitudes (305 m and 457 m) within a three weeks period when the distribution of the beluga was expected to remain relatively stable (Gosselin et al. 2007). The purpose was to evaluate the effect of the change in altitude on beluga abundance estimation from visual line transect surveys, but results revealed a more important variation between daily estimates than between altitudes. Variations of up to 150% and 200% were noted between successive daily abundance estimates at the two altitudes, whereas variations up to 175% and 300% were observed between surveys flown at a similar altitude over the three weeks survey period. This study also revealed that the three components of the estimation of abundance, i.e. effective strip half width, cluster size and encounter rate were variable between daily surveys. The variations in abundance in the St Lawrence estuary study were similar to those observed between surveys or passes in James Bay and eastern Hudson Bay.

The accuracy and precision of abundance estimates can be improved in several ways. An increase in survey effort by a reduction of spacing between lines would likely increase the number of groups detected, reduce the portion of the study area over which extrapolation of the results is applied and therefore further reduce the importance of each cluster on the abundance estimate. However, a maximal survey effort does not solve all the problems, as indicated by the study in the St Lawrence Estuary, where survey effort and effective strip width covered more than a quarter of the area surveyed and where extreme variations in abundance were still observed between surveys conducted a day apart (Gosselin et al. 2007). In eastern Hudson Bay, transect spacing is currently [illegible] nautical miles, or 9.3 km, for which effective strip half width of 1000m represent effective coverage of more than 20% of the area surveyed. This leaves limited room between lines to reduce spacing before running into the problem of double counting.

Adaptive sampling is another approach to increase the detection of animals in areas of detected high densities (Pollard & Buckland 2004; Thompson & Seber 1996). However, given the current line spacing in the high coverage area, there is little opportunity for more intensive sampling when concentrations are detected. On the other hand, adaptive sampling might be a viable option in the low coverage areas of eastern Hudson Bay. However, few beluga groups were detected in these areas in past surveys and so, the usefulness of this approach might be limited in the context of beluga surveys in Nunavik and James Bay.

The probability of group detection could also be increased through better understanding of habitat use and distribution. This knowledge would allow for a re-evaluation of the stratification of the survey area based on daily or short-term movements of individuals. This stratification might lead to an increase in the number of sightings during a survey, which would provide a more accurate, and possibly more precise estimations of mean cluster size and encounter rate. In eastern Hudson Bay and James Bay, recent information on habitat use could be obtained through a spatial analysis of past survey data (Smith & Hammill 1986; Kingsley 2000; Gosselin et al. 2002; Gosselin 2005; this study), satellite telemetry data (Lewis et al. 2009; Hammill, unpublished data), and traditional ecological knowledge (Lewis et al. 2009). However, the large variations in the distribution of beluga that have been observed between past surveys, from a complete shift of the animals from the south of James Bay in 1985 and 2004 to the north in 1993, 2001 and 2008, might pose some limits to further stratifications (Figure 7 in Gosselin 2005). Nevertheless, some areas appear to be used repeatedly over time, such as the sectors located along the northwest coast of James Bay and to the north of Akiminski Island. Clearly, a rigorous spatial analysis of the data available might reveal interesting patterns worth considering for the design of future surveys.

Following the survey conducted in 2001, it was suggested to lower the altitude of the planes to decrease chances of missing available animals at the surface near the trackline (Gosselin 2005). The effect of changing altitude from 457 m (1500 feet) to 305 m (1000 feet) was tested in the St Lawrence Estuary where beluga densities are higher (Gosselin et al. 2007). It was concluded that the effect of the change in altitude from 457 m to 305 m was minor compared with the extreme variations in daily abundance estimates. Although the effect of changing altitude should not be ignored, efforts should rather be directed towards maximizing the number of beluga detections.

So in conclusion, one way of dealing with clumping for the three components of line-transect estimation, particularly for encounter rate and expected cluster size is to increase the effort to have more observations for each of the three components and to reduce the relative importance of each observation in the abundance estimate. However, with the actual 5 nautical miles spacing in eastern Hudson Bay and with estimated effective coverage of 20%, there is only limited room for increased effort through reduction in spacing between lines or through the use of adaptive sampling. Another way to increase effort is to repeat surveys as we did in 2008. But as seen in 2008 and as we saw in the St Lawrence estuary experiment, improvement of results may require several surveys, and this would mean an extended period of survey in a given season, where, in eastern Hudson, we would run into the problems of migrations by September. Another solution to increase effort would be to reduce the number of years between surveys. A better understanding of movements and habitat use within the summer season to allow better stratification of survey design could be achieved or at least assessed through spatial analyses of previous surveys, of satellite telemetry and traditional ecological knowledge. However, complex stratification of survey design should be done with care, and the current knowledge of movements and the details in the habitat use information that we have or the analyses that have been done, does not allow for the development of complex stratified survey design.

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Table 1. Summary of strata effort and observations detected

Stratum	Area (km^2)	Effort (km)	Number groups	Number individuals
James Bay	78,234	4,279	214	853
Eastern Hudson Bay				
low coverage area	27,223	1,246	1	1
high coverage area first pass	64,087	6,756	108	326
high coverage area second pass	"	6,513	47	120
Richmond Gulf	705	82	1	3
Ungava Bay low coverage area	46,524	2,336	0	0
high coverage area	18,331	1,998	0	0

Table 2. Density and abundance estimation for James Bay and eastern Hudson Bay in summer of 2008, showing results for the sub-strata of eastern Hudson Bay. These estimations include clusters within truncation distances and clusters that were detected without perpendicular distances but that were assumed to be within truncation distances. Coefficients of variation are shown in parenthese

Stratum	N groups	Effective strip half width (m)	Sighting rate (group/km)	Mean cluster size	Surface index of abundance	Abundance 95% CI	Density	Density 95% CI
James Bay	214	839.27 (0.08)	0.0500 (0.56)	3.99 (0.31)	9,292(0.64)	2,828-30,530	0.119	0.036-0.390
Eastern Hudson Bay low cov.	1		0.0008 (1.01)	1 (0)	13 (1.02)	3 - 102	0.0005	0.00006-0.0038
Richmond Gulf	1		0.0122 (1.03)	3.00 (0)	15 (1.03)	3 - 136	0.0219	0.0025-0.1931
EHB high coverage 1st pass	107		0.0158 (0.22)	2.97 (0.13)	1,797(0.27)	1,055-3,062	0.0280	0.0160-0.0480
EHB high coverage 2nd pass	45		0.0069 (0.21)	2.49 (0.30)	657 (0.38)	319-1,353	0.010	0.005 - 0.021
Average for high coverage:					1,237(0.46)			
Total in eastern Hudson Bay:					1,265(0.45)	545 - 2,939		

Table 3. Indices of beluga populations in James Bay, eastern Hudson Bay and Ungava Bay estimated from five systematic aerial surveys. The 1985 survey data were collected using strip-transect techniques (Smith and Hammill 1986). The other four surveys flew along the same lines as the 1985 surveys, but data were collected using line-transect techniques (Kingsley 2000; Gosselin et al. 2002; Gosselin 2005; this study). Data from 1993 and 2001 were re-analysed assuming a strip width of 1000 m on each side of the aircraft to adjust the 1985 survey estimates by multiplying the strip-transect estimates by a line transect-strip transect ratio and then adding in estuary counts (Gosselin 2005).

		Systematic offshore estimate	Abundance estimate		
		Strip-transect	Strip-transect	Richards line-transect	Distance line-transect
Stratum	Year	$\hat{N}_s$ (SE)	$\hat{N}_s$ (SE)	$\hat{N}$ (SE)	$\hat{N}$ (SE) [95% CI]
James Bay	1985	1213 (290)	1213 (290)	*1842*	*2,256*
	1993	2296 (566)	2296 (566)	3141 (787)	3922 (781) [2645–5816]
	2001	4732 (712)	4732 (712)	7901 (1744)	8262 (1687) [5463–12,495]
	2004				3998 (1078) [2379–6721]
	2008				9292 (5985) [2828-30,530]
EHB	1985	968 (165)	1442 (165)	*2089*	*2,294*
	1993	688 (205)	706 (205)	1032 (421)	1,314 (489) [631–2761]
	2001	620 (263)	659 (263)	1194 (507)	1,418 (635) [615–3339]
	2004				2045 (698) [1052–3982]
	2008				1,265 (570) [545 - 2,939]
Ungava Bay	1985	0	0	0	0
	1993	0		88	0
	2001	0		0	0
	2004				No survey
	2008				0

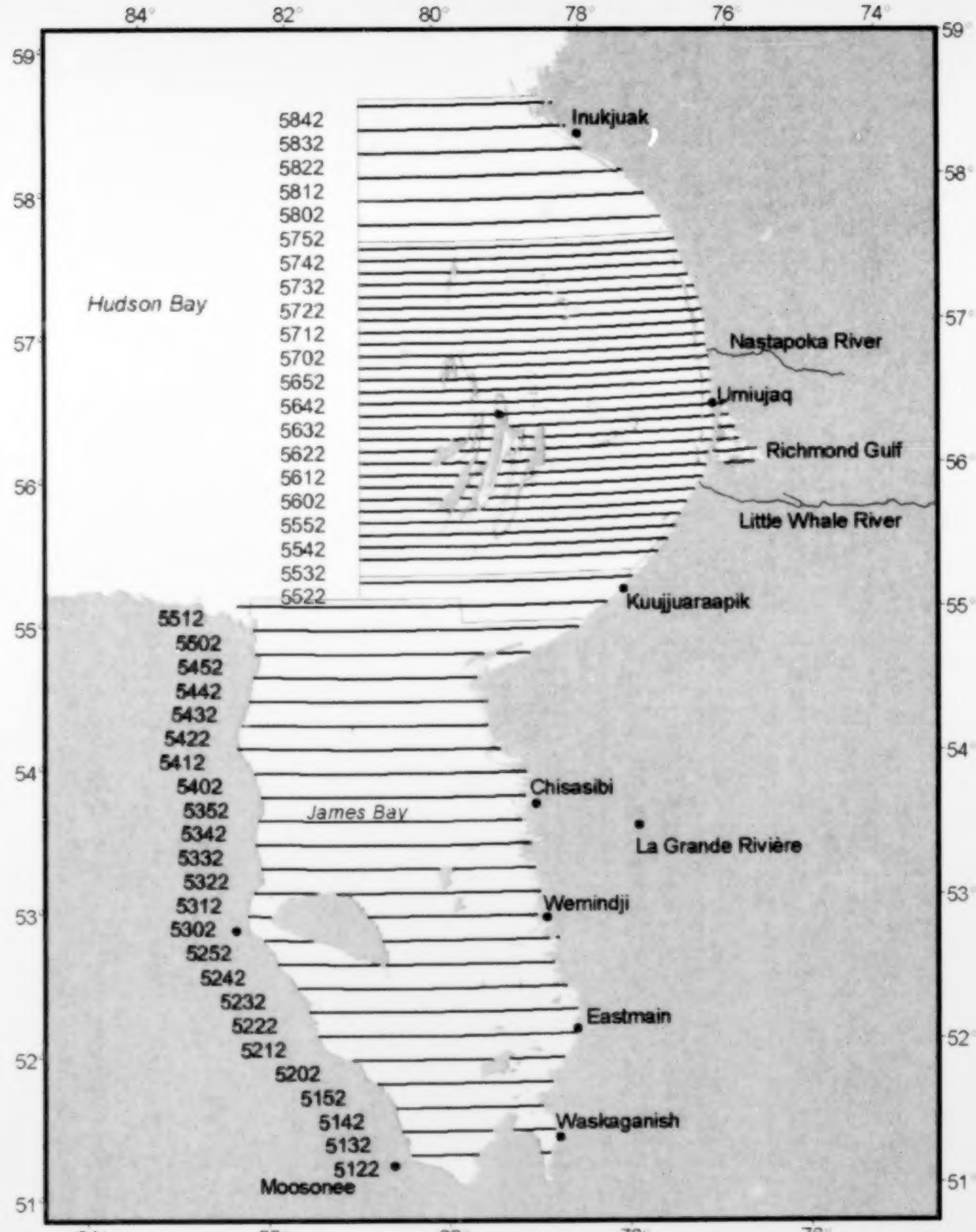


Figure 1. Transect lines surveyed in James Bay and eastern Hudson Bay from 20 July to 19 August 2008. The thin lines show the limits of James Bay and the low and high coverage strata in eastern Hudson Bay.

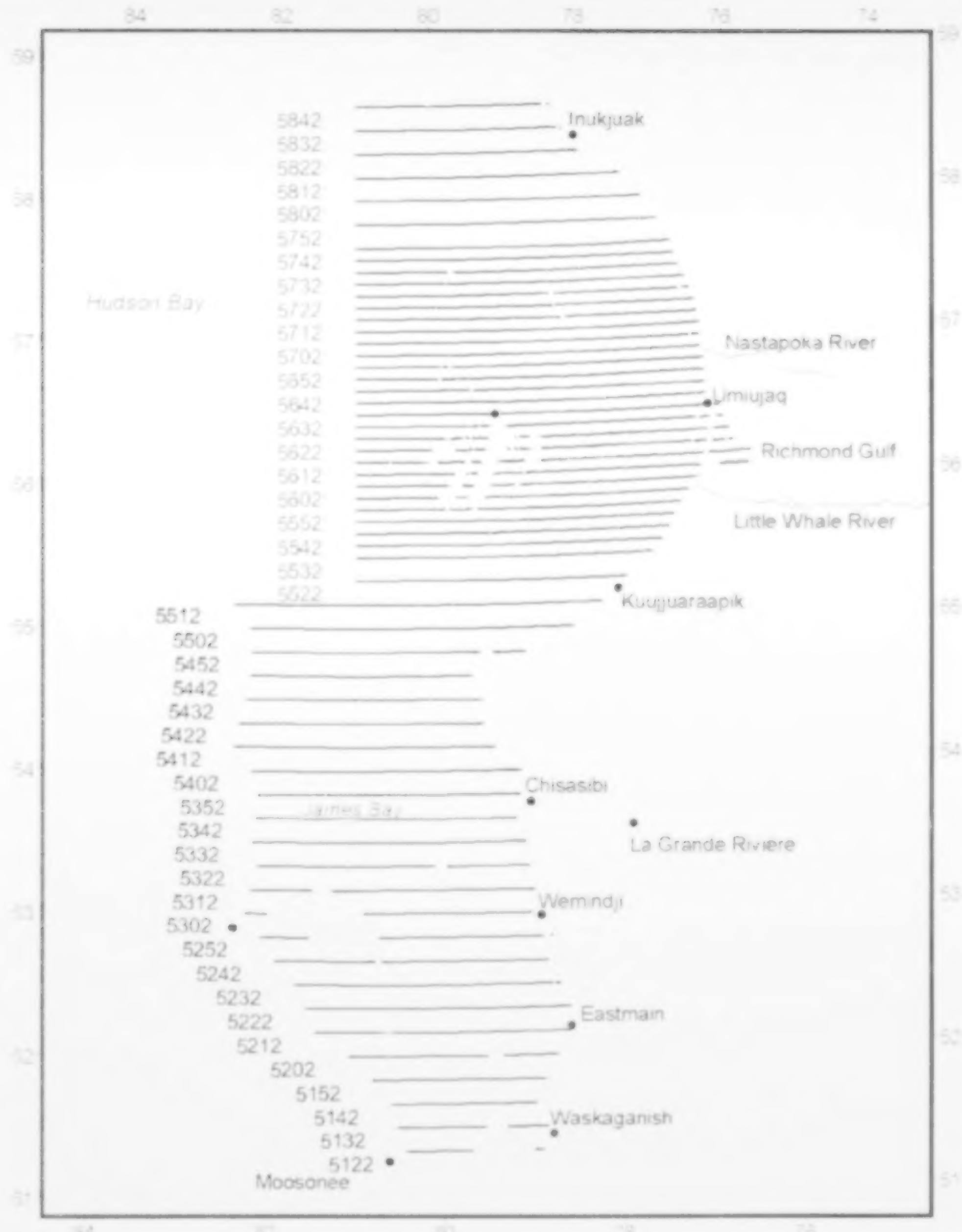


Figure 1. Transect lines surveyed in James Bay and eastern Hudson Bay from 20 July to 19 August 2008. The thin lines show the limits of James Bay and the low and high coverage strata in eastern Hudson Bay.

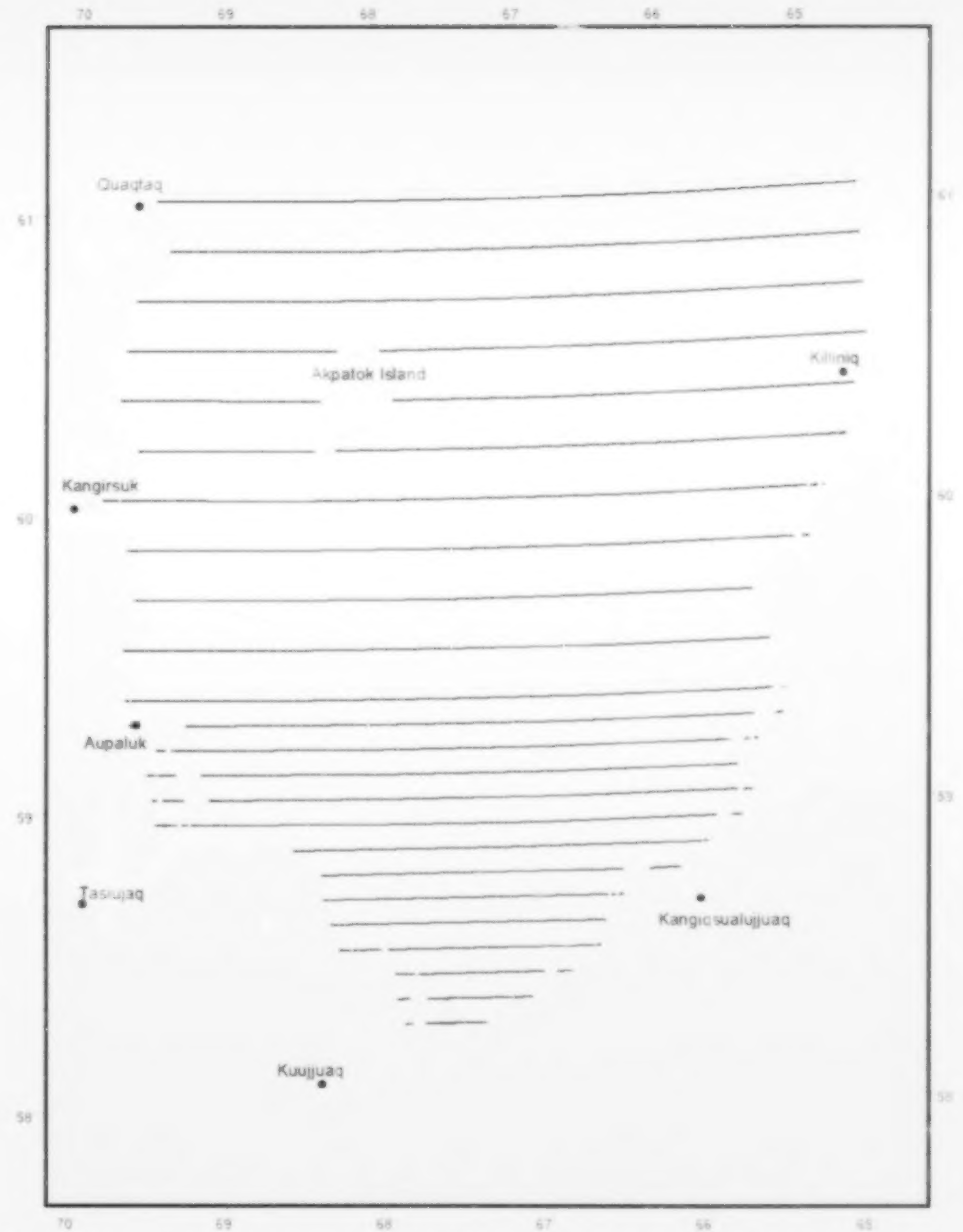


Figure 2. Transect lines surveyed in Ungava Bay from 20 to 28 August 2008. The thin lines show the boundaries of the low and high coverage strata.

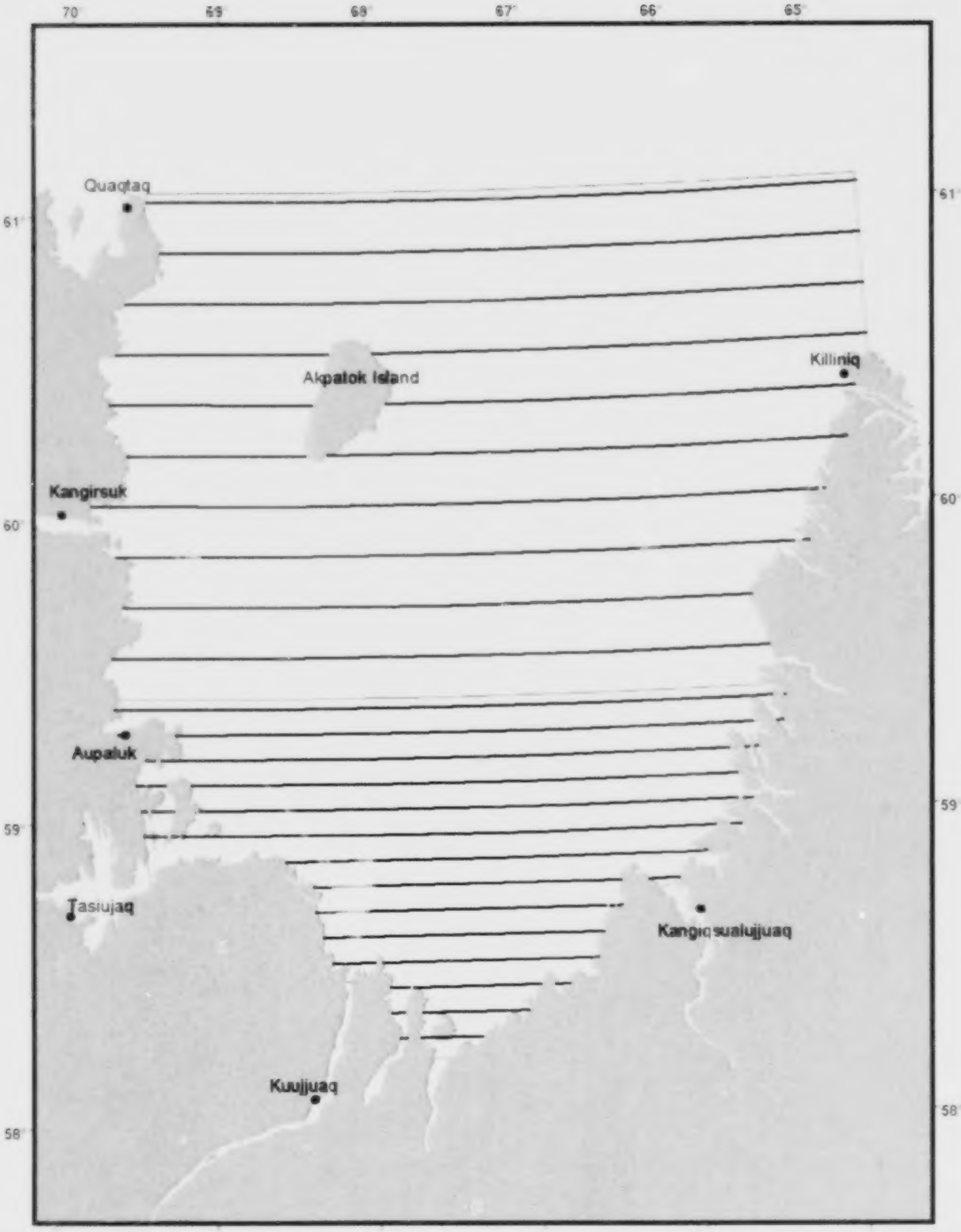


Figure 2. Transect lines surveyed in Ungava Bay from 20 to 28 August 2008. The thin lines show the boundaries of the low and high coverage strata.

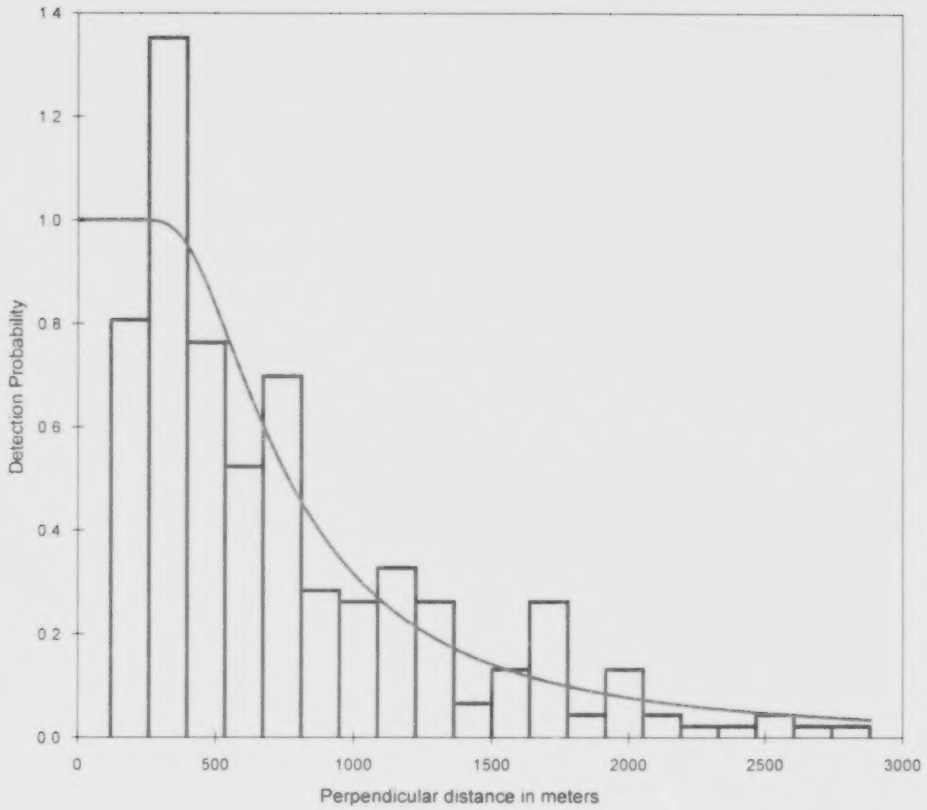
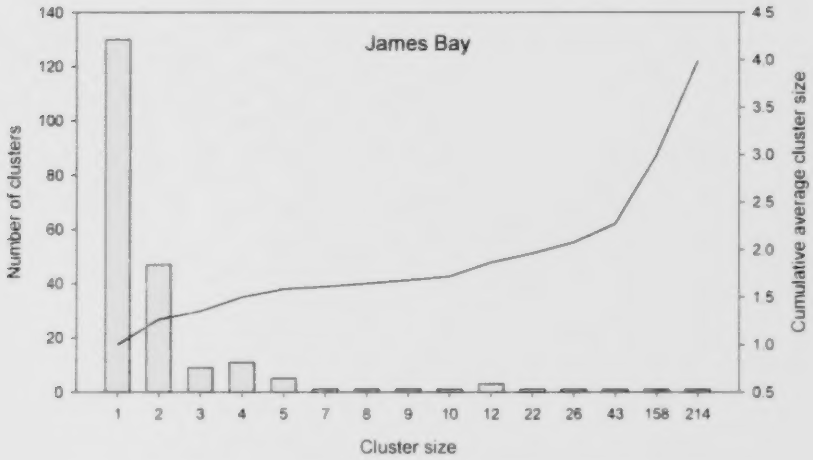
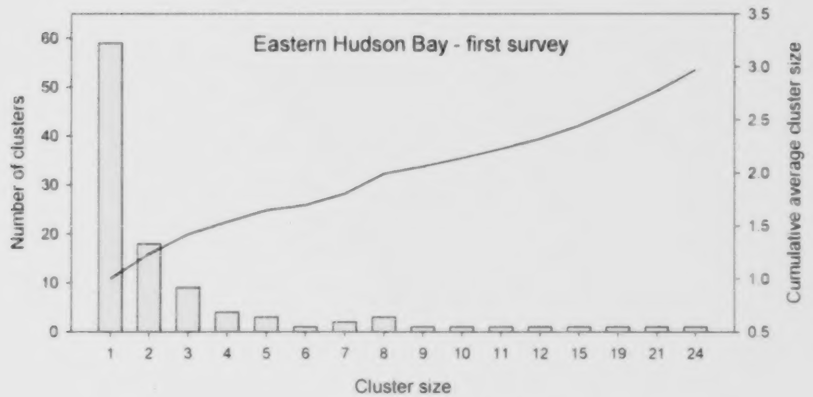


Figure 3. Distribution of perpendicular distances of 279 clusters of beluga whales detected in James Bay and eastern Hudson Bay and the fitted hazard rate detection function providing an effective strip half width of 839 m. The perpendicular distances are grouped in 20 bins, but the model was fitted to the ungrouped dataset.





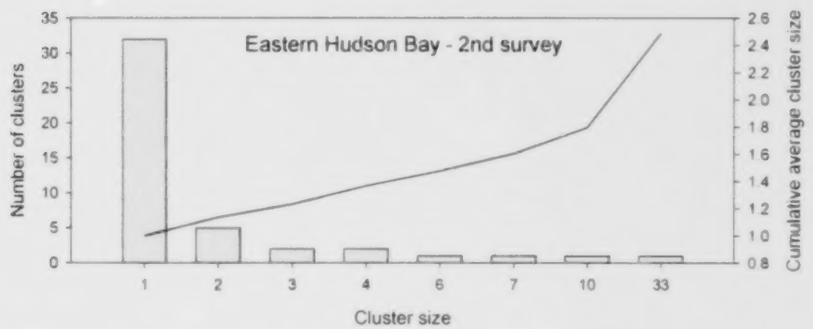


Figure 4. Frequency distribution of cluster sizes in James Bay and the two survey of eastern Hudson Bay. The cumulative average cluster size shows the effect of of large clusters on the expected cluster size for the stratum.

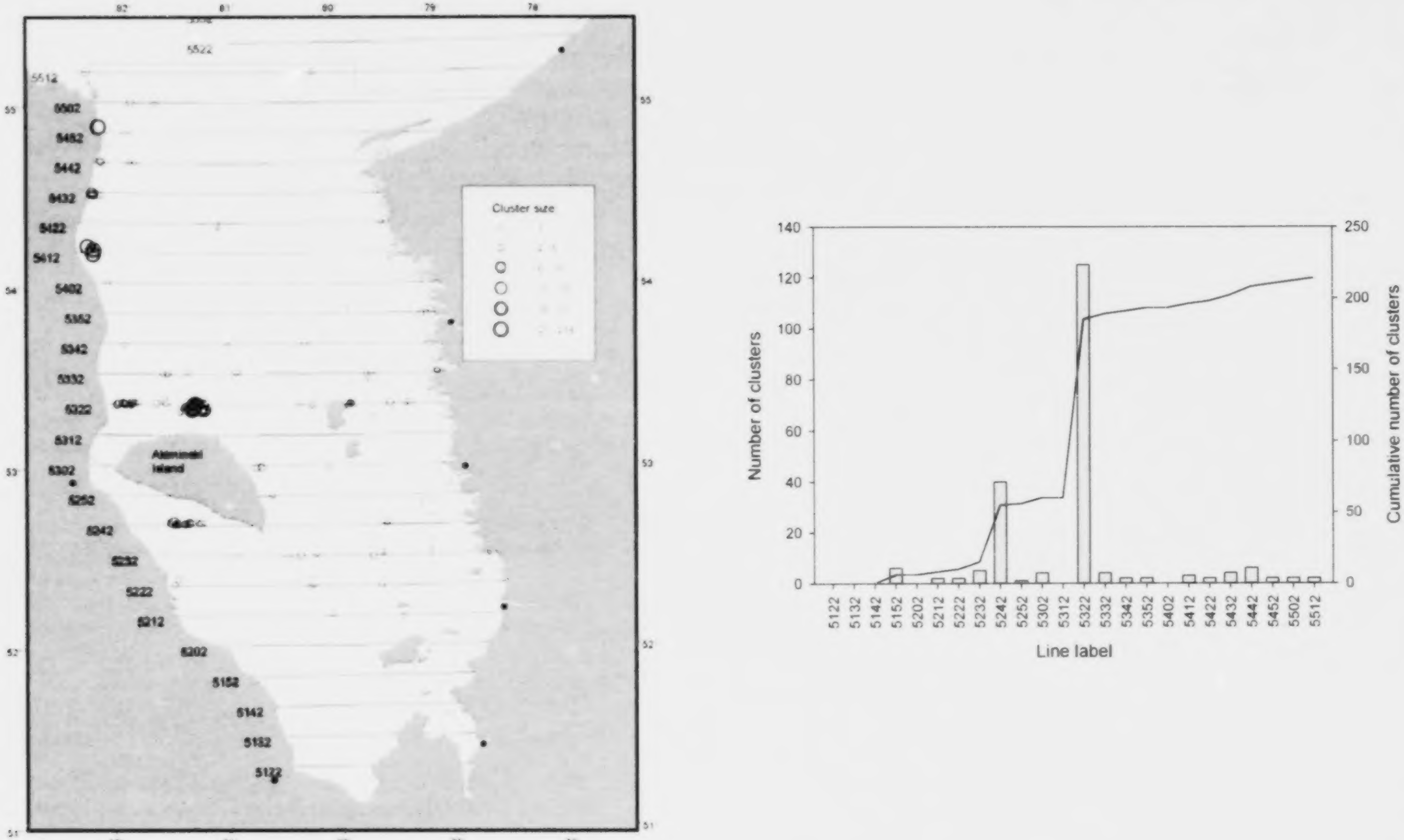


Figure 5. Geographic distribution of detected clusters along with the frequency of the number of clusters detected per line and the cumulative number of clusters from south to north in James Bay.

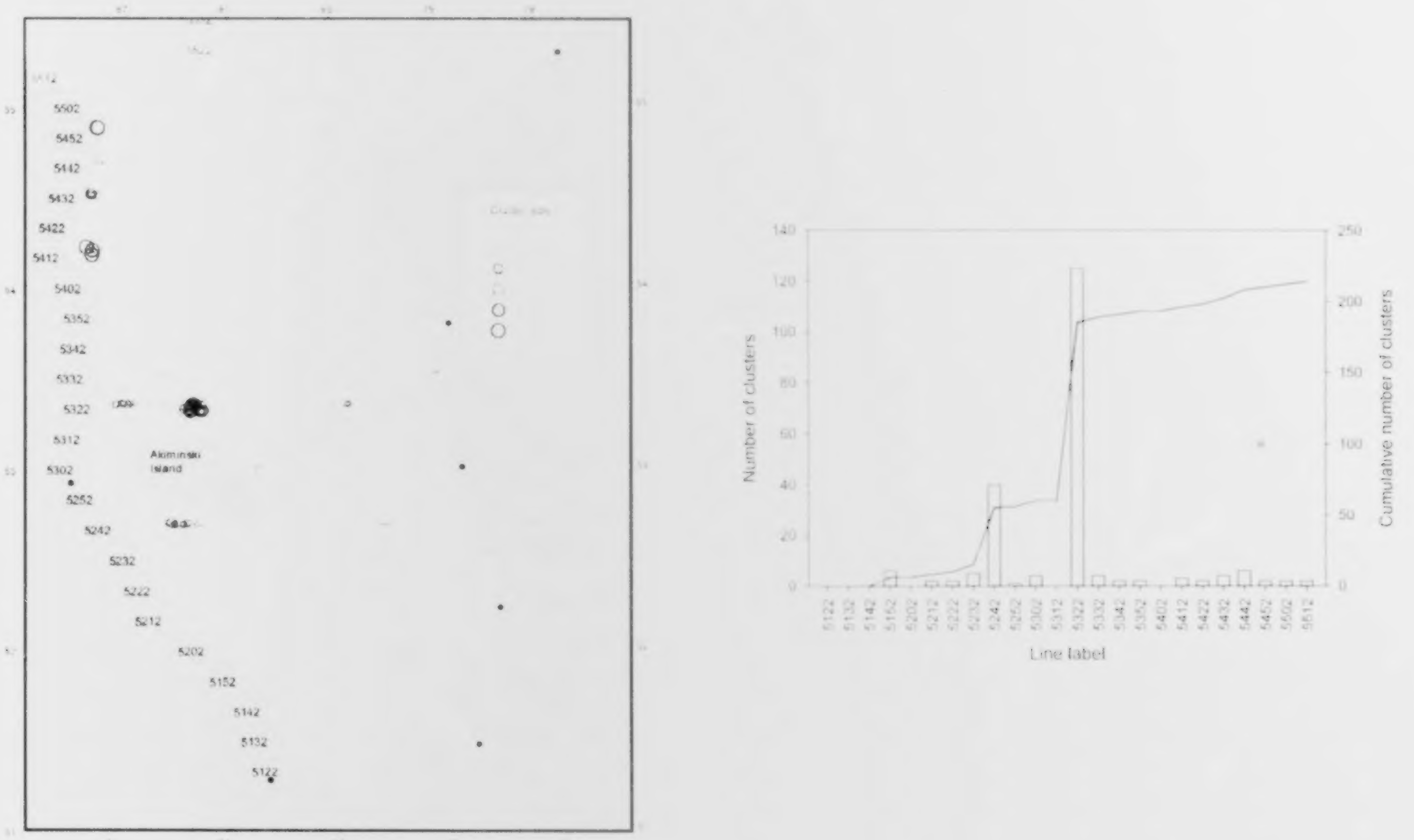


Figure 5. Geographic distribution of detected clusters along with the frequency of the number of clusters detected per line and the cumulative number of clusters from south to north in James Bay.

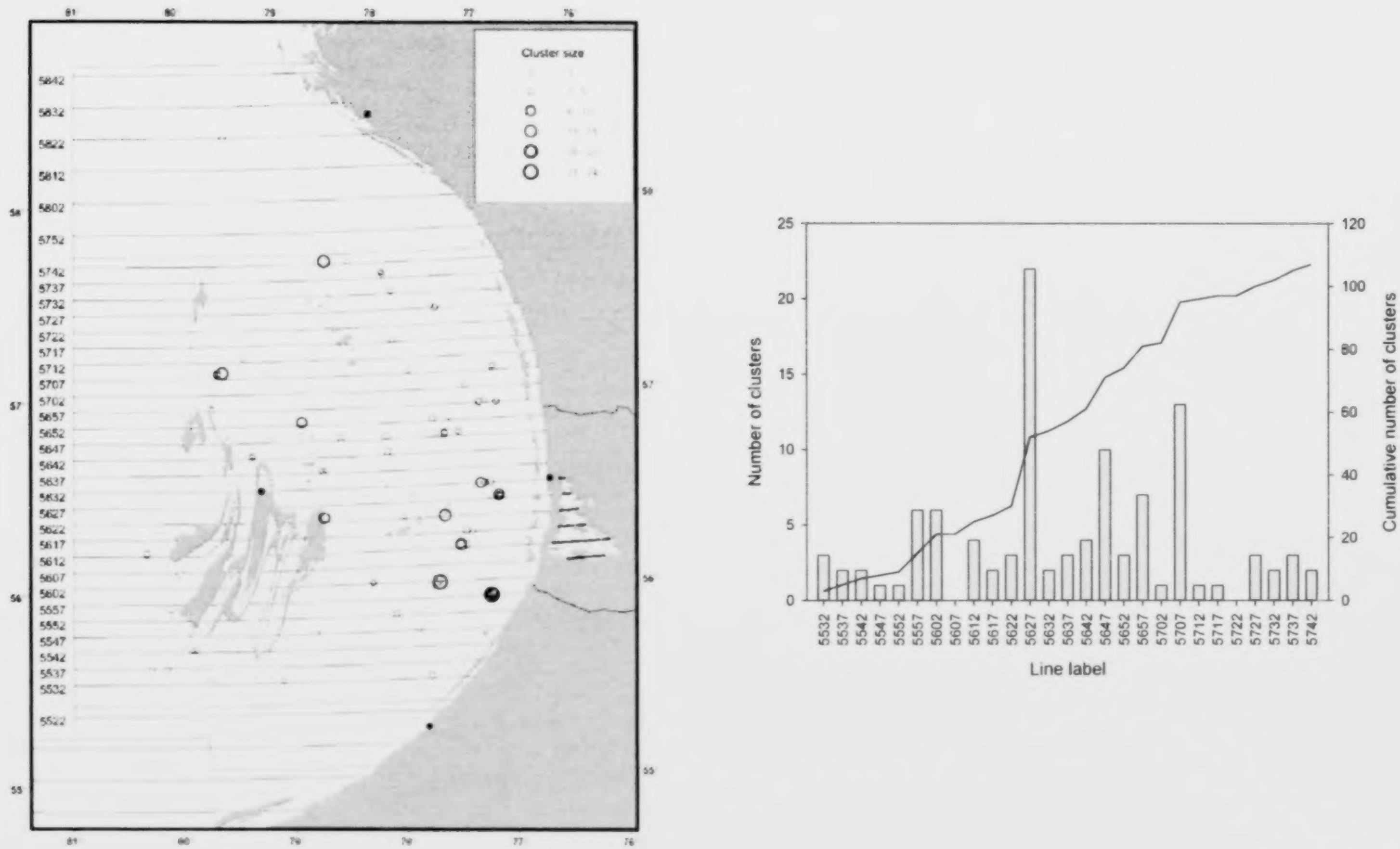


Figure 6. Geographic distribution of detected clusters along with the frequency of the number of clusters detected per line and the cumulative number of clusters from south to north during the first survey of eastern Hudson Bay.

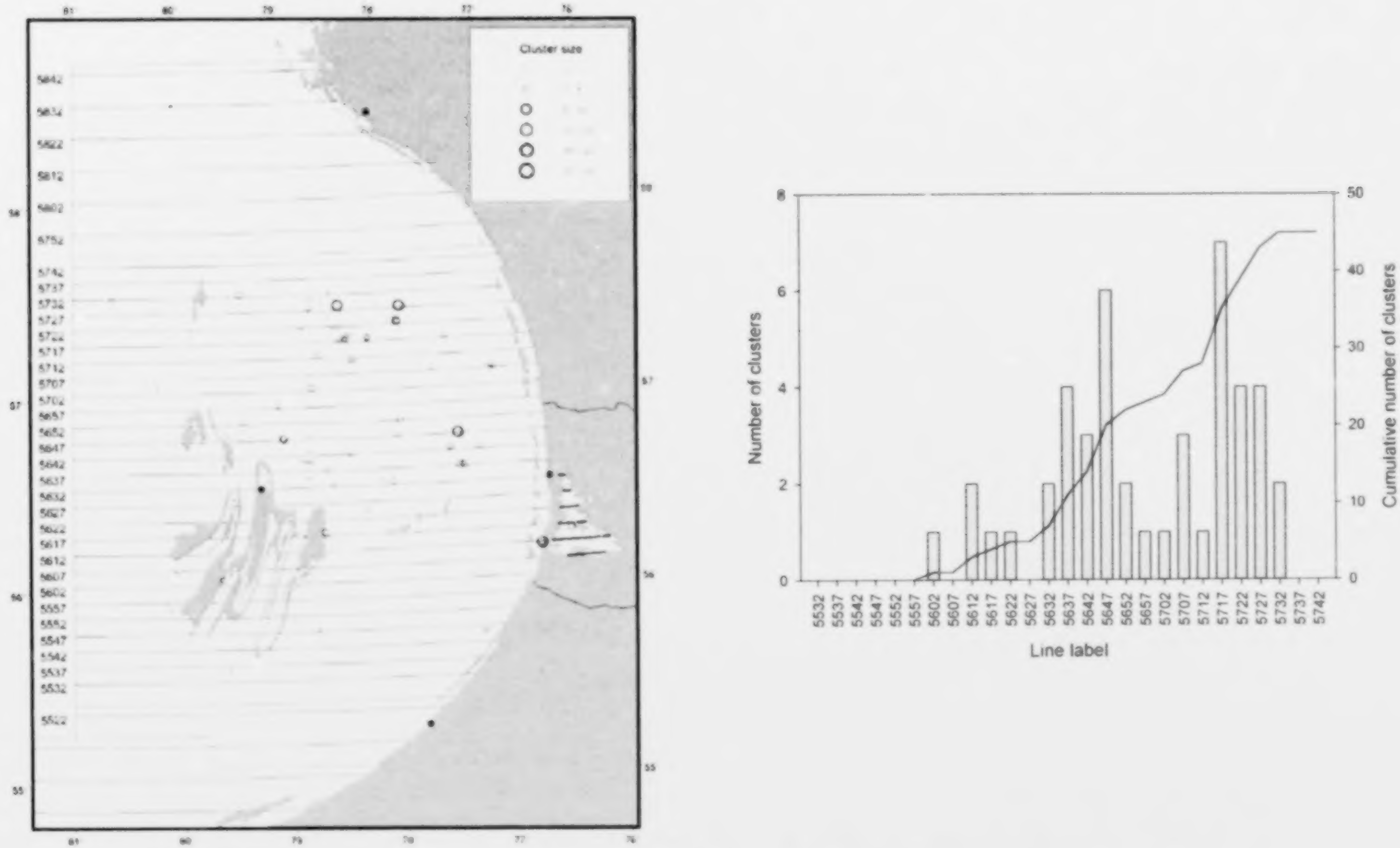


Figure 7. Geographic distribution of detected clusters along with the frequency of the number of clusters detected per line and the cumulative number of clusters from south to north during the second survey of eastern Hudson Bay.